

Chapter 6

Directions of the future

6.1 Is the seismic inverse problem solved?

6.1.1 What is the seismic inverse problem?

The seismic inverse problem is to obtain all physical properties of rocks from the observations of seismic waves. Only some properties have a significant effect on the waves and can thus be resolved. The greater the effect on the waves the better resolved the property. The seismic inverse problem is complicated because seismic waves are nonlinearly related to the rock properties, seismic source wavelets are band limited, and source and receiver arrays are aperture limited.

In this thesis, I have identified the most important properties to be the high- and low-wavenumber components of the P- and S-wave velocities and derived elastic inversion formulas to obtain these properties. I tested my elastic inversion formulas on synthetic and field data.

High wavenumbers in velocity are resolved by amplitudes of reflected waves while low wavenumbers in velocity are resolved by traveltimes of reflected, diffracted and transmitted waves. The method of inversion assumes the Earth is a 2D elastic isotropic medium and uses nonlinear least squares to find Earth properties corresponding to synthetic seismic data that best matches the observed wavefield. This method requires an “adequate” initial model and assumes that the statistics of the noise and model are Gaussian. If this requirement is unmet or if the assumptions are invalid, the solution will degrade in quality and be less correct from the probabilistic viewpoint.

6.1.2 Solving for the initial model

For convergence to the global minimum, the initial velocity model must be adequately accurate. In particular, the low-wavenumber components of this model must be such that the kinematics of waves are well modeled. If not, the algorithm may still converge depending on aperture because the traveltimes and amplitudes of events must be matched. However, the convergence would be slow. The interval velocities near the shot would converge first with the region of convergence expanding as the iterations proceed and the kinematics of the waves are well modeled further from the shot.

The slow convergence of the low-wavenumber components of the velocity when the initial model is inaccurate implies that a better understanding is required of how the inversion formulas resolve the low-wavenumbers. With a better understanding, one could perhaps obtain the low wavenumbers rapidly while avoiding the requirement for a good initial model.

6.1.3 Accounting for everything

Seismic waves are not 2D elastic waves. They suffer attenuation, are anisotropic to varying degrees, and are three dimensional. Furthermore, there are other factors to be accounted for such as unknown geophone couplings, source strengths and source wavelets. Ideally, the inversion algorithm should be extended to include all these effects. However, as we have seen with the low-wavenumber velocities, it is crucial to understand exactly where in the inversion formulas the different parameters are resolved. Only then, can we obtain a complete inversion formula that takes everything into account in an optimal way while still obeying the true physics of the system.

6.1.4 Statistics

The inversion formulas are based on Gaussianity assumptions for data noise and model statistics. Another area for improvement would be to allow for arbitrary statistics. This is a problem applicable to all inverse problems. Even if such a technique were available that allowed for arbitrary statistics efficiently, it may be difficult to choose the appropriate statistical model in practice. Therefore, while arbitrary statistics may be philosophically appealing, their inclusion is far from being realized and they are of unknown value in practice.

6.1.5 Parallelism, physics and inverse physics

The beauty of the method presented in this thesis is that everything that can be resolved by the multitude of standard processing methods can be obtained by a single set of equations and these only require waves to be simulated. This is easy because the physics of wave propagation is well understood. Furthermore, macroscopic physics is a parallel process, that is to say, molecules vibrate independently of one another. Therefore, wave simulations are ideally suited to fine grain parallel computers enabling rapid computation of the equations of inverse physics to obtain the Earth properties.